

METHODS FOR IMMUNO-DETECTION OF EPITOPES ON MOLECULES AND
FOR DETECTION OF INTERACTIONS OF MOLECULES VIA FLUORESCENT
DYES

Introduction

5 This application is a continuation-in-part of U.S.
Patent 09/783,896, filed February 15, 2001, which is a
continuation-in-part of U.S. Patent Application Serial No.
09/624,946, filed July 25, 2000.

Background of the Invention

10 Traditional methodologies for protein detection and
quantification include 2-D gel electrophoresis, mass
spectrometry and antibody binding. Each methodology has
been used to quantify protein levels from relatively large
amounts of tissue, yet each suffers from a lack of
15 sensitivity.

Improvement of the ability to monitor proteins,
lipids, sugars and metabolite levels and their modifications
is needed for cell biology and medicine. A variety of
technologies have been employed to improve the sensitivity
20 of detecting these molecules. Recent examples of detection
methods include immuno-PCR, RCA and immuno-aRNA.

Immuno-PCR (U.S. Patent 5,665,539) combines the
polymerase chain reaction (PCR) technology with conventional
detection methods to increase the sensitivity to detect
25 protein. However, a major limitation of immuno-PCR lies in
the non-linear amplification ability of PCR reaction, which
limits this technique as a quantitative detection method.
Thus, this method provides no direct correlation between the
amount of signal and the amount of protein present.

30 A relatively isothermal rolling circle DNA
amplification technique (RCA; Schwietzer et al., Proc. Natl.

Acad.Sci. USA 97, 10113, 2000)) provides an improvement over immuno-PCR as this technique overcomes some of the quantitation problems associated with immuno-PCR.

U.S. Patent 5,922,553 discloses a method for
5 quantifying levels of a selected protein via a technique referred to as immuno-aRNA. In this method, a first antibody targeted to a selected protein is immobilized to a solid support. The support is then contacted with the selected protein so that the selected protein is immobilized
10 to the first antibody. The solid support is then contacted with a RNA promoter-driven cDNA sequence covalently coupled to a second antibody targeted to the selected protein so that the second antibody binds to the bound selected protein. The amount of selected protein is determined by
15 quantifying levels of the promoter driven cDNA sequence covalently coupled to the bound second antibody via an amplified RNA technique. In a preferred embodiment, a T7 promoter driven cDNA sequence is covalently coupled to the second antibody.

20 It has now been found that single chain fragments as well as exocyclic peptide based complementarity determining region (CDR) subunits can be used in this immuno-aRNA technique. Further, it has been found that PCR, as well as amplified RNA techniques, can be used to quantify the
25 promoter driven cDNA sequence covalently coupled to the bound single chain fragment or CDR subunit. The use of smaller antibody binding units and fragments coupled with the already existing large single chain or cyclic peptide libraries and the use of robotic assistance renders this
30 method widely useful for both medicinal and research purposes. Furthermore, a single third detector species can be coupled with double-stranded DNA and bound to either the single chain Fv or the CDRs, rendering detection uniform and simple.

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Summary of the Invention

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An object of the present invention is to provide a method for detecting molecules expressing a selected epitope in a sample. In this method, an epitope anchor specific for 5 a selected epitope is immobilized to a selected surface. The epitope anchor may comprise a single chain Fv fragment, a CDR, CDR mimetic or engineered CDR structure, an antibody, or other ligand peptide or chemical or pharmaceutical that interacts with a selected epitope. The surface is then 10 contacted with a sample suspected of containing molecules which express the selected epitope so that the molecules bind to the immobilized epitope anchor. An epitope detector comprising a single chain Fv for the selected epitope or a constrained epitope specific CDR, CDR mimetic or engineered 15 CDR structure attached to an oligonucleotide, preferably a double-stranded cdna, is then used to detect any bound molecules. The oligonucleotide can be chemically conjugated or linked through biotin-streptavidin or biotin-avidin binding to the single chain Fv, CDR, CDR mimetic or 20 engineered CDR structure. Alternatively, the method of the present invention can be performed without an epitope anchor. In this embodiment, the epitope detector is employed to define molecules bound directly to a surface.

In a preferred embodiment of this method, detection 25 is performed via readout using a standard fluorimetric device of a fluorescence derived numerical value. More specifically, in this embodiment, following amplification of the oligonucleotide of the epitope detector, a fluorescent dye is incorporated into the nucleic acid 30 sequence in a linear manner. Upon excitation at a selected wavelength, the dye yields a quanta of fluorescence signals directly proportional to the mass of sample loaded.

With a mixture of epitopes detectors comprising either monoclonal antibodies for selected epitopes, single 35 chain Fvs for selected epitopes or constrained epitope

specific CDRs, CDR mimetics or engineered CDR structures, conjugated to cDNAs of different lengths, the method of the present invention can also be used to profile proteins in a cell lysate.

5 In one embodiment, CDRs, CDR mimetics or engineered CDR structures for use in the epitope detector are identified via screening of a library of CDRs, CDR mimetics or engineered CDR structures to define a CDR, CDR mimetic or engineered CDR structure which binds a molecule with the
10 epitope. CDRs or CDR mimetics identified via screening of these libraries can also be used as therapeutic agents targeted to a receptor or protein interacting with the receptor. When used as a therapeutic agent, it is preferred that the CDR or CDR mimetic be reinserted into a humanized
15 antibody or attached to an Fc.

Another object of the present invention is to provide kits for the detection of molecules expressing a selected epitope which comprise an epitope detector comprising a single chain Fv for the selected epitope or a constrained
20 epitope specific CDR, CDR mimetic or engineered CDR structure attached to an oligonucleotide, preferably a double-stranded cDNA. In addition, the kits preferably comprise an RNA polymerase, an amplification buffer and a fluorescent dye for staining of amplified products. Kits
25 of the present invention may further comprise an epitope anchor specific for a selected epitope. In one embodiment, the single chain Fv or the constrained epitope specific CDR, CDR mimetic or engineered CDR structure is modified to allow for attachment of the oligonucleotide. In another
30 embodiment, the kit comprises a mixture of epitope detectors for profiling of proteins in a cell lysate.

Methods and kits of the present invention can be formulated into a convenient 96- or 384-well plate platform for high-throughput handling and screening of samples.

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Methods and kits of the present invention are particularly useful in analyzing the interactions of molecules , e.g. protein-protein interactions, ligand-induced protein-protein interactions and sugar-protein interactions, as well as for monitoring changes in these interactions which are induced by chemicals, pharmaceuticals and other molecular species including, but not limited to, proteins, lipids and sugars.

Detailed Description of the Invention

- 10 The present invention relates to improved methods for quantifying levels of selected molecules and systems and kits for performing these improved methods. In one embodiment, the method comprises binding an epitope anchor specific for a selected epitope of the molecule to a
- 15 selected surface. The epitope anchor may comprise a single chain Fv fragment, a CDR, CDR mimetic or engineered CDR structure, an antibody, or other ligand peptide or chemical specific for a selected epitope. In a preferred embodiment, the epitope anchor is bound to a designated spot on the
- 20 surface. For example, the surface may comprise a chip and the epitope anchor is bound to a defined spot on the chip. In one embodiment, the epitope anchor is deposited onto a surface or plate with the aid of a pipettor or similar device which permits application at a single site. The
- 25 surface with the bound epitope anchor is then contacted with a sample suspected of containing molecules expressing the selected epitope so that the molecule binds to the epitope anchor. In another embodiment, the molecule is attached to a surface directly, without the use of an epitope anchor.
- 30 Examples of samples which can be assayed via the methods of the present invention include, but are not limited to, individual cells and solutions including biological fluids such as serum.

5 An epitope detector which can bind to any bound molecule on the surface is then used to detect and quantify the amount of bound molecule. The epitope detector comprises a monoclonal antibody, a single chain Fv for the selected epitope or a constrained epitope specific CDR, CDR mimetic or engineered CDR structure or which have been modified to allow for attachment of oligonucleotides, preferably double-stranded DNA at a single site. Alternatively, fragments of antibodies with the binding activity, scFv or CDR peptides can be used to replace antibodies in this technology.

Fv fragments for selected epitopes can be produced in cells or on microorganisms by use of recombinant DNA technology. For example, Skerra and Pluckthun (Science 1988 240:1038-1044) describe an expression system for production of functional Fv fragments in *E. coli*.

A method for producing Fv fragments in eukaryotic host cells with a eukaryotic expression vector which has an operon having a DNA sequence which encodes the variable domain only of an antibody light or heavy chain has also been described (J. Mol. Biol. 1988 203:825-828). Chains of the Fv fragment are secreted and correctly assembled by the host cell such that fully functional Fv fragments are produced in the culture supernatant. In addition, the DNA coding sequence may be altered toward its 5' end so that the amino terminal end expresses a residue or residues with a surface suitable for covalent coupling of an oligonucleotide. In addition, the 3' terminal end may be varied so that cysteine residues are produced towards the C-terminal end of each variable domain permitting the variable domains in the dimer to become linked together by disulphide bonding. This may also promote assembly of the Fv fragment. Alternatively, the Fv fragment may be stabilized by use of a vector having a first DNA sequence encoding a first variable domain and a second DNA sequence

encoding a second variable domain, the first and second sequences being linked by a third DNA sequence which encodes a joining peptide sequence. In this case, the joining peptide sequence is sufficiently long and flexible to allow
5 folding of the two polypeptides into a functional single chain Fv. Preferably, the host cell is a myeloma cell line which, prior to transformation, does not secrete whole antibody or light chains. Such cells lines are well known and widely available (Reichmann et al. J. Mol. Biol. 1988
10 203:825-828).

It is believed that random phage technology to any hapten or chemical compound can also be used to select Fvs. (Harrison et al. United States Biochemical Pharma Ltd. (Europe), Watford, United Kingdom)

15 The CDR technology is well known and has been described in U.S. Patent 5,334,702, U.S. Patent 5,663,144, and U.S. Patent 5,919,764. Antibody molecules bind to their antigens via six variable loops called Complementary Determining Regions (CDRs). The CDR3 from heavy chain often
20 mediates that specificity. A general methodology for design of constrained cyclic CDR mimetics is described by Williams et al. (Proc. Natl Acad. Sci. USA 1989 86:5537-5541), Sargovi et al. (Science 1991 253:792-795) and Murali et al. (Immunol. Res. 1998 17:163-169). In general, CDRs comprise
25 a 6 to 15 mer peptide constrained to be cyclic and modified by aromatic residues. CDR mimetics are small molecules (about 1 kDa) which are capable of mimicking their parent antibodies in terms of specificity, affinity and biological activity. Cyclic forms of CDR mimetics contain
30 approximately 5 to 13 constrained amino acids.

For purposes of the present invention, an epitope detector or epitope anchor comprising a CDR may consist essentially of the CDR or CDR mimetic. Alternatively, the epitope detector or epitope anchor may comprise a CDR or
35 CDR mimetic defined as binding which is reinserted into a

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humanized antibody framework or attached to an Fc. CDRs or CDR mimetics reinserted into a humanized antibody or attached to an Fc are also referred to herein as engineered CDR structures. However, as will be understood by those of skill in the art upon reading this disclosure, the term "engineered CDR structure" is inclusive of any protein into which a CDR or CDR mimetic is inserted. Examples of such proteins include, but are not limited to, members of the immunoglobulin gene family, minibodies or small antibody-like molecules, or any other framework which allows the CDR to be functional as an antigen binding surface.

An important step in the design of CDRs, CDR mimetics and engineered CDR structures for use in the present invention is the delineation of the residues that are
15 important for activity. This is generally accomplished by first synthesizing a set of analogs from the bioactive domain of the original antibody or receptor or ligand of different lengths and establishing the minimal chain lengths for the complete and partial activities. Once the minimal
20 chain length has been established, each side chain can be systematically varied to determine the importance of charge, steric bulk, hydrophobicity, aromaticity, and chirality at each position. After evaluation of the properties of a large set of analogs, it is possible to identify the
25 functional groups and conformation features involved in binding. Different conformationally constrained analogs can then be developed. Various means for constraining peptides have been developed.

One means involves introducing a conformationally
30 constrained amino acid. Hruby (Life Sci. 1982 31:189-199)
describes the synthesis of a large number of amino acid and
dipeptide derivatives with built-in conformational
constraints, as well as their incorporation into
biologically active peptides. Prasad et al. (Biopolymers
35 1995 35:11-20) also describes a method of constraining the

conformation of an amino acid unit by replacing the hydrogen atom at the α -carbon with a methyl group to produce a dialkylamino acid. U.S. Patent 6,022,523 describes a method that restricts the conformational freedom of amino acids by
5 introducing a double-bond at the C- α and C- β atoms.

Another means for constraining peptides involves introduction of covalent cross-links. Constraining the peptide backbone by introduction of covalent cross-links provides more dramatic effects than incorporating unusual
10 amino acids. Macrocyclization is often accomplished by forming an amide bond between the peptide N- and C-termini, between a side chain and the N or C terminus, or between two side chains. A head-to-tail cyclization of side protected peptides synthesized by Fmoc/t-butyl solid phase procedures
15 on polysterine resin derivatized with 4-hydroxymethyl-3-methoxyphenoxyacetic acid, the first generation dialkoxybenzyl linkage agent, has been described by Sheppard, R.C. (Int. J. Peptide Res. 1982 20:451-454). In addition, the analogous linkage agent, 4-(4-hydroxymethyl-3-methoxyphenoxy)-butyric acid (HAMA), was recently employed
20 in fragment condensation and solid phase synthesis of peptides with these highly acid sensitive linkers (In Peptides, E. Giralt and D. Andreu eds, ESCOM, Leiden, The Netherlands 1991, 131-133). The enkephalin analogs
25 described by Schiller provide an example of side-chain to backbone covalent cyclization in which covalent attachment of the ϵ -amino group of the D-lys residue to the C terminal backbone carboxylate group of Leu produces a cyclic 16-membered ring analog with high potency and significant μ
30 receptor selectivity (Schiller et al. Int. J. Pep. Prot. Res. 1985; 25:171-177). BOP-reagent and carboimide/1-hydroxy-benzotriazole combinations have also been reported to be useful in the formation of cyclic peptides (Felix, A.M. Int. J. Pep. Prot. Res. 1988 31:231-238). Degrado et
35 al. have also developed a biologically active cyclized

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peptide analog of the GP IIb/IIIa complex using m-aminomethylbenzoic acid as the linker (U.S. Patent 6,022,523).

Disulphides can also be formed by oxidation via
5 introduction of cysteine at certain positions. For example, Romani, S. (Int. J. Pep. Prot. Res. 1987 29:107-117) demonstrated that non-symmetrical disulphides can be built with the help of the di-tertbutyl ester of azodicarboxylic acid. Ploux, O. (Int. J. Pep. Prot. Res. 1987 29:162-169)
10 also describes a method for formation of non-symmetrical disulphides via thiol displacement of the 3S-3-nitro-2-pyridinesulphenyl group.

In a preferred embodiment, the oligonucleotide used in the present invention is double-stranded and comprises
15 a T7 promoter driven cDNA sequence so that it can be amplified using T7 RNA polymerase. In this embodiment, double-stranded cDNA is synthesized for use as a template for T7 RNA polymerase transcription. T7 RNA polymerase requires its promoter site to be double-stranded.

20 In one embodiment, the site on the Fv or CDR, CDR mimetic or engineered CDR structure to which the oligonucleotides are attached comprises a series of residues which allow the attachment of linkers consisting of chemicals such as heterodimeric coupling reagents or other
25 linkers. These residues provide a uniform binding site for the linker attachment. The linkers attach to this site and also link oligonucleotides to the Fv or CDR, CDR mimetic or engineered CDR structures. Oligonucleotides may be unmodified or modified. For example, the presence of the
30 amplified oligonucleotide can be enhanced by incorporating a beacon or fluorescent labeled oligonucleotide into the mixture allowing for rapid semi quantitative assessment of the epitope expressing molecules (Ton et al. Chemistry 2000 6:1107-1111; Leone et al. Nucleic Acids Res. 1998
35 26(9):2150-2155).

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In another embodiment, the oligonucleotide of the epitope detector is coupled to biotin and the monoclonal antibody, single chain Fv or constrained epitope specific CDR, CDR mimetic or engineered CDR structure is coupled to streptavidin and attachment of the oligonucleotide to the monoclonal antibody, single chain Fv or constrained epitope specific CDR, CDR mimetic or engineered CDR structures occurs via complexing of the biotin to the streptavidin.

Bound epitope detectors may be quantified by methods such as amplification by conventional PCR or aRNA techniques. If the detection method used is immuno aRNA, double-stranded cDNA are preferably used in the epitope detector. In this embodiment, aRNA is transcribed on the solid support using a polymerase, unlabeled ribonucleotides, and fluorescently labeled ribonucleotides. By "polymerase" for purposes of the present invention, it is meant a polymerase which recognizes a specific promoter. Examples of polymerases useful in the present invention include, but are not limited to, T7 RNA polymerase, T3 RNA polymerase, SP6 RNA polymerase, ϕ 29 polymerase, and Taq polymerase. In another embodiment, the amplified products can serve as templates for further amplification with reverse transcriptase or replicases to increase the sensitivity.

A variety of means are available for detection of amplified products of the epitope detector. In one embodiment, the nucleic acid sequence is detectably labeled such as with a radioactive label or a fluorescent label. In a preferred embodiment, the nucleic acid sequence is not labeled but rather is stained by fluorescent dye. Other methods such as gel electrophoresis, high performance liquid chromatography, hybridization assays, immunohistochemical assays and/or specific binding protein assays can also be used for detection.

Use of Fvs and CDRs, CDR mimetics or engineered CDR structures as the epitope detector renders the methods of

the present invention useful in identifying larger polypeptides than can be identified by the immuno-aRNA technique of U.S. Patent 5,922,553, as well as in identifying motifs in supernatants, fluids, extracts of
5 cells or bacteria or any other eukaryotic organism. Accordingly, the method of the present invention has widespread applicability in both medicinal and research purposes. Further, the method of the present invention is more sensitive than currently available methods and provides
10 quantitative results.

The ability of Fvs and CDRs, CDR mimetics or engineered CDR structures to serve as epitope detectors of selected molecules in the method of the present invention was demonstrated for the p185 receptor. For these
15 experiments, a single chain Fv (ScFv) construct of 7.16.4 (designated as 7.16.4 ScFv) was produced in accordance with the procedure outlined by Peterson & Greene (DNA and Cell Biology 1998 17(12):1031-1040) wherein the Fv region of the heavy chain and light chain region was joined by a
20 (gly4-Ser)5 linker. Since ScFv7.16.4 contained a poly-histidine tag, it was purified over Ni-NTA resin. After purification, the binding of 7.16.4ScFv was confirmed by FACS analysis on B104-1-1 cells, in both direct binding and competitive binding against the monoclonal antibody
25 7.16.4.

AHNP, a constrained exocyclic peptide designed from the CDR3.H region of the anti-human p185 antibody 4D5 was also used. AHNP binds to p185 and mimics the growth-inhibitory effects of 4D5 (Park et al. Nature Biotechnology
30 2000 18:194-198).

Both ScFv7.16.4 and AHNP were coupled to a double-stranded oligonucleotide (ds-oligo) to form epitope detectors. Both ds-oligo coupled 7.16.4ScFv and AHNP were able to detect their antigens, rat p185neu from B104-1-1
35 cells and human p185her2/neu from T6-17 cells, respectively.

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Further, conjugation with the ds-oligo to form the epitope detector did not change the binding affinity of the CDR detection molecules with their antigens as determined by plasmon resonance analysis. Since 7.16.4ScFv and mAb 7.16.4 have comparable binding affinity against the p185 receptor, they were used at comparable molar concentration in this assay. However, AHNP was used at a higher concentration since its affinity is lower against p185Her2/neu than 4D5.

AHNP was also expressed as a streptavidin fusion protein using the M13 phage system. The cDNA for the core streptavidin sequence from *Streptomyces avidinii* was cloned by PCR using a 5'PCR primer which also contains the sequence for a (Gly4Ser)₂ linker. Complementary oligonucleotide encoding AHNP and an additional Gly4Ser linker were synthesized and annealed to form the double strand DNA. After ligation, the fusion consists of AHNP at the N-terminus of a (Gly4Ser)₃ linker followed by the core streptavidin (SA) sequence. The linker region is introduced to produce flexibility between the tetrameric AHNP mimetic and SA which normally resembles a tetramer. Both long linkers comprising 3 or more Gly4Ser linkers and short linkers comprising 2 or 1 linkers be used in these fusion proteins. However, longer linkers of 3 Gly4Ser linkers are preferred as they provide for greater flexibility.

The fusion construct was cloned into the SalI-ApaI site in the phage expression vector phage3.22 (Maxim Biotechnology, CA). The fusion was expressed first in the pIII phage protein reading frame of the TG1 bacterial strain. AHNP-SA fusion can also be expressed in another bacterial host strain (HP2151) free of the pIII component. A chimeric protein consisting of the extracellular domain of p185Her2/neu and the immunoglobulin Fc region (Her2-Fc) was used to test the binding affinity of the expressed AHNP-SA forms. Her2-Fc was coated onto a 96-well immunoassay plate and the phage supernatant was added to the plate.

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Biotin-conjugated peroxidase was then used to detect binding activity of AHNP-SA molecule to purified Her2-Fc.

Thus, since, as shown herein, the AHNP-SA species is amenable to polymerase-based amplification when attached to a biotinylated oligonucleotide, the AHNP-SA species provides a vehicle to develop a rapid and diverse proteomics approach.

A CDR mimetic of anti-EGFr molecules, AERP, which a different number of constrained amino acids has also been developed and shown to have nM affinity for EGFr.

A preferred means for detection in the present invention comprises staining with a fluorescent dye. In this embodiment, after RNA amplification with a polymerase such as T7 RNA polymerase, T3 RNA polymerase, SP6 RNA polymerase, ϕ 29 polymerase or Taq polymerase, a portion of the reaction mixture can be mixed with a fluorescent dye such as RiboGreen reagent (Molecular Probes, Inc) (U.S. Patent 5,436,134), a unsymmetrical cyanine dye that binds to RNA directly in the solution and then releases fluorescence signals. Examples of other fluorescent dyes with similar properties useful in this method include, but are not limited to, PicoGreen, TOTO-1 or YOYO-1. The reactions are preferably performed in microplates and the fluorescence is read using a fluorimeter such as the Spectra Fluora 5 to 15 minutes after mixing RNA solutions with RiboGreen dye.

In the method of the present invention, a mixture of epitope detectors comprising either monoclonal antibodies to selected epitopes, single chain Fvs for selected epitopes, or constrained epitope specific CDRs, CDR mimetics or engineered CDR structures, conjugated with cDNAs of different lengths can be used in a single reaction to probe the cell lysate to provide a profile of proteins in the cell lysate via automatic sequencing. In this method, after amplification and staining of the amplified products with

a fluorescent dye, the reaction mixture is separated by electrophoresis and the size of the RNA products are visualized by fluorescent dyes or probes. Moreover, specific probes can hybridize with the reaction mixture and reveal the presence and abundance of the corresponding antigens.

The sensitivity of the fluorescence detection method of the present invention was demonstrated for the p185 receptor. In these experiments, a chimeric p185-Fc polypeptide was first coated directly to a 96-well plate. The 4D5 monoclonal antibody conjugated with a 1 kb cDNA was then used to detect the chimeric p185-Fc receptor. Since the cDNA contained a T7 promoter, it was amplified by the T7 RNA polymerase. After amplification, the RNA product was mixed with the RiboGreen reagent in a 96-well plate and excited at 485 nm after 5 to 10 minutes. The fluorescent reading was collected at 535 nm. Using this method, concentrations as low as 0.177 pg/ml were detected.

Coupling of a ds-oligo directly to the CDR or single chain Fv can be a time-consuming procedure, particularly if the purpose is to detect hundreds or thousands of antigens in a mass screening proteomic assay. In addition, variation in the coupling efficiency can complicate the interpretation of the amplification results. Accordingly, in a preferred embodiment of the present invention, the Fv or CDR contains a general or universal epitope such as an hemagglutinin HA tag or polyhistidine tag. An example of a general or universal epitope is the poly-His-tag in the 7.16.4ScFv initially designed for the purification of the protein. A single monoclonal antibody or single chain Fv coupled with ds-DNA is then used to bind to the general epitope to create a universal epitope detector. The efficacy of a universal epitope detector in the method of the present invention was demonstrated with the poly-His-tag in the 7.16.4ScFv. In these experiments, p185 receptors

were captured by A11 coated on the plate, free 7.16.4ScFv was added, followed by extensive washing and then incubating with ds-oligo conjugated anti-His antibody. After T7 polymerase amplification, specific bands from lysates of 5 10^{-6} dilution of the cells were detected. Accordingly, this sensitivity was even higher than that seen with the basic protocol without a universal epitope detector.

The method of the present invention is also useful in the detection of post-translation modifications. PCR and 10 aRNA techniques were originally developed to detect the activity of target genes at the DNA level. These methods have been adopted exclusively in the application of genomics research, sometimes combined with hybridization. Regardless of sensitivity, these methods are not able to detect the 15 post-translation modification at the protein level. Monitoring of such events, however, is very critical since many modifications including, but not limited to, phosphorylation and glycosylation are related to the functional status of the protein. Thus, experiments were 20 performed to demonstrate the ability of the method of the present invention to detect the phosphorylation of the p185 receptor induced by EGF treatment. A signaling model was established in which, upon EGF stimulation, EGFR heterodimerizes with and trans-activates p185, resulting in 25 the phosphorylation of tyrosine residues on the p185 receptor (Qian et al. Proc. Natl Acad. Sci. 1994 15:1500-1504). The A431 cell line, which overexpresses EGFR as well as p185 erbB2, was used in these experiments. After EGF stimulation, the p185 receptor in the cell lysate was 30 captured by 1E1, a monoclonal antibody developed against p185erbB2/neu. PY99, an IgG2b type of anti-phosphorylated Tyr antibody, was used to detect phosphorylated receptors. A second antibody, anti-IgG2b, coupled with ds-oligo, was used to probe the antigen-antibody sandwich complex. A431 35 cells stimulated with EGF produced a positive band, which

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was not observed in cells without EGF treatment. T6-17 cells, however, also showed a positive band, indicating constitutive phospho-tyrosine on the p185 receptor. These data indicate that this method is capable of detecting the functional status of a protein by analyzing its modification. Epitope detectors comprising an Fv or CDR coupled to the ds-oligo can also be used to detect the functional status of the protein.

Thus, the present invention provides a sensitive detection method which eliminates concerns about the non-quantitative nature of immuno-PCR techniques and which offers vast potential in the field of proteomics. By using a polymerase which recognizes a specific promoter such as T7 RNA polymerase, T3 RNA polymerase, SP6 RNA polymerase, ϕ 29 polymerase or Taq polymerase as well as the specific promoter in the amplification step, assays performed in accordance with this method possess linear amplification and precise quantification which are relevant to biological and medical assays. The number of factors that affect the sensitivity of detection have also been reduced. The specific binding between antigens and their Fv or monovalent CDR, CDR mimetic or engineered CDR structure is the only critical parameter of this method.

The ability to provide universal epitope detectors provides the method of the present invention with multiple additional advantages. First, any cellular antigens can be detected without having been first coupled to a monoclonal antibody with ds-oligo. Without the universal probe, the method would only be useful in looking at one or several particular antigens at a time. The universal probe, on the other hand, allows for the detection of any cellular or fluid residing antigen with available Fvs or CDRs, CDR mimetics or engineered CDR structures. In addition, with slight modification in the protocol, different proteins can be detected simultaneously in a single electrophoresis lane

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when oligonucleotides of different sizes are attached to the Fv or CDR, CDR mimetic or engineered CDR structure of the epitope detector. Thus, as demonstrated herein, the method of the present invention provides a versatile technique that is applicable in the identification of protein antigens as well as post-translational modification of polypeptides and other structures such as sugars or lipids at the single cell level of detection.

The method of the present invention is also useful in the analysis of interactions of molecules and the detection of small molecules. For example, ligand peptides can be used as epitope detectors on tissue samples to identify the expression of specific receptors, or verse visa. With available Fvs, CDRs, CDR mimetics or engineered CDR structures, or binding proteins, small molecules such as toxins or drug metabolites, can be detected in any solution including, but not limited to, water, foods, and body fluids.

To study the interactions of molecules, a two-component (molecule A/molecule B) interaction system is developed. The two components, molecule A and molecule B may comprise proteins, sugars, or other types of chemical entities including, but not limited to, carbohydrates, DNA or RNA, or peptides with structural conformations such as alpha helices or beta-sheets. To develop this two-component system, an epitope detector such as an antibody for a first molecule, referred to hereafter as molecule A, is placed in proximity with a sample comprising molecule A so that molecule A binds to the epitope detector. A solution containing products of an expression library constructed so that each expressed protein also contains a HA tag or similar tag can then be added to identify molecules which interact with molecule A. For purposes of the present invention, these molecules are referred to herein as molecule B or a second molecule. Alternatively, normal

cellular extracts or lysates or any fluid containing potential molecule B can be used.

If the second molecule, molecule B, in the library product or cellular extract or lysate binds to the first molecule A bound by the epitope detector, the new molecules can be detected with either a universal detector that binds to the tag or marker or by the use of a CDR library or a scFv library specific against molecule B. In a preferred embodiment, monitoring of the interaction between molecule A and molecule B is performed by the fluorescence based quantifiable assay which detects the amplified nucleic acid sequence from the oligonucleotide conjugated to the universal detector.

When one of the molecules of the two-component (molecule A/molecule B) interaction system binds a ligand or pharmaceutical drug, the two-component system can be used to investigate the effects of the ligand or drug on the binding of molecule A to molecule B. Accordingly, the present invention also provides an *in vitro* system for monitoring drug affects on interactions of molecules. The ligand or drug can be added at any step in the assay to determine how the ligand or pharmaceutical drug alters the binding of molecule A to molecule B. In addition, more than one drug can be added to the two-component interaction system. For example, a second drug such as an antagonist of the first drug can be added and the level of binding of A to B as well as to the complex of A and B can be determined. Further, instead of known ligands or drugs, a third solution containing the products of another library of molecule C marked with other tags could be added to the complex of A and B and the effects of this third solution on binding can be determined.

Thus, the present invention provides a rapid *in vitro* screening assay with a biological readout, namely the formation of a complex interaction. Further, using this type

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of system it is possible to build screening systems that act like organic analogue computers whose output is dependent on the number of events developed with each progressive addition. These progressive events are disturbed upon
5 addition of a third molecule such as a pharmaceutical drug or ligand that interferes with this assembly. The quantification of signals before and after addition of the third molecule defines the change in output. A positive change means that the pharmaceutical drug or ligand
10 facilitates the binding of molecule A to molecule B, while a negative change means that the pharmaceutical drug or ligand inhibits the binding of molecule A to molecule B.

Active CDRs, CDR mimetics or engineered CDR structures can also be used as starting template molecules to derive a
15 spectrum of CDRs, CDR mimetics or engineered CDR structures to identify and study via the present invention families of proteins associated with a particular disease state, i.e the erbB family and its association with origin and early detection of malignancy. For example, a library has been
20 developed containing a large and diverse population of CDR mimetics ($>10^6$) of a single ring size that develop into constrained turns and also possess aromatically modified termini. This particular library was produced using the M13 phage system and contains a large repertoire of CDR-
25 streptavidin binding moieties diversified from a 6 membered AHNP peptide through randomization. For diversification of the library, the synthesized oligonucleotide library encoding randomized CDR regions, but with a fixed constrained framework region, are inserted into the phage construct that
30 leads to the expression of the highly varied CDR streptavidin fusion proteins.

CDR-SA libraries can be used in the present invention, for example, to screen transformed cell lines and tumor cells for tumor surface markers. In this embodiment, initial
35 screening preferably employs fluorescence based

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microfluorimetry for binding to cells followed by an ELISA type assay for binding to captured proteins derived from cell lysates. For example, a monoclonal antibody can be attached to PI3-kinase or ras and any bound CDR-SA forms can be detected. The sequence of any unknown targets of tumor specific selected CDR-SA molecules can then be determined. In one embodiment, purified CDR-SA is used to screen a cDNA expression library constructed in cells such as COS7 cells and in expression libraries prepared from freshly isolated tumor tissues from various stages of malignancy.

Libraries of CDRs, CDR mimetics or engineered CDR structures can also be used to generate a spectrum of probes to detect receptors, proteins associated upon activation of the receptors and proteins involved in pathways associated with the receptors. For example, a CDR mimetic library can be used to generate a spectrum of probes to erbB receptors, proteins associated upon activation of erbB receptors and proteins involved in pathways associated with erbB receptors such as the PI-3 kinase pathway.

CDRs or CDR mimetics of libraries defined as binding to a receptor, proteins associated upon activation of a receptor or proteins involved in pathways associated with the receptor are can also be used therapeutically to target the receptor or protein. In a preferred embodiment for therapeutic use, the CDR or CDR mimetic is reinserted into a humanized antibody framework or attached to an Fc. In this embodiment, the engineered CDR structure may be administered alone or may further comprise a radiolabel or cytotoxin attached thereto.

Methods for preparing scFv libraries with some randomly changed CDRs are described by Winter et al. in U.S. Patent 6,291,650, U.S. Patent 6,225,447, U.S. Patent 6,172,197 and U.S. Patent 6,140,471. However, production of CDR-SA libraries are not described by Winter et al.

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Also provided in the present invention are kits for performing the methods of the present invention. In one embodiment, a kit is provided for the detection of molecules expressing a selected epitope. In a preferred embodiment, 5 detection of the molecule is performed via a fluorescent dye which stains nucleic acid sequences. Thus, this kit preferably comprises an epitope detector comprising an oligonucleotide attached to a monoclonal antibody for the selected epitope, a single chain Fv for the epitope or a 10 constrained epitope specific CDR, CDR mimetic or engineered CDR structure, as well as an RNA polymerase, an amplification reaction buffer, and a fluorescent dye. In another embodiment, kits are provided for profiling proteins in a mixture such as a cell lysate. In this embodiment, the kit 15 preferably comprises a mixture of epitope detectors comprising monoclonal antibodies for selected epitopes, single chain Fvs for selected epitopes or constrained epitope specific CDRs conjugated with cDNAs of different lengths, as well as an RNA polymerase, an amplification reaction buffer, 20 and a fluorescent dye.

The original immuno-PCR used pure antigens in the assay. Later iterations of immuno-PCR examined mixed antigens (Hendrickson et al. Nucleic Acids Research 1999 23(3):522-529) but only showed sensitivity of two to three 25 orders of magnitude higher than ELISA. In a real-world assay with the background comprising a huge variety of non-specific antigens, sensitivity is always limited by the specificity of the assay. Epitopes bound by the Fvs or CDR fragments are expected to identify larger polypeptides and can be used to 30 identify motifs in supernatants, fluids, extracts of cells or bacteria or any other eukaryotic organism. Further, actual identity of the polypeptides, organic molecules or sugar structures can be determined by computer aided analysis of data bases using the binding of several epitopes by Fvs 35 as a guide. For example, binding by Fv a, d, e, and f would

identify a sugar molecule as having side chains a, d, e, and f, and hence belonging to a family of sugars having these same side chains. In this way the present invention allows definition and identification of many, if not all molecules in a cell at any one particular time. Moreover this approach can be used to identify alternative transcriptional forms translated in an active cell or cellular supernatant. This procedure is easily amenable to 1) use with nonradioactive detection methods, most preferably fluorescent dyes 2) microtized liquid handling procedures, 3) low sample volume detection such as "protein chip" analysis and 4) robotization. For example, a chip can be developed which contains multiple binding elements or units and a single universal epitope detector. A binding element that recognizes a common surface on the monoclonal antibody, the single chain Fv, or the CDR, CDR mimetic or engineered CDR structure, such as a universal antibody can be used. Alternatively, avidin can be built into each antibody, single chain Fv or CDR, CDR mimetic or engineered CDR structure and biotin can be coupled to the oligonucleotide. These chips provide the advantage of more rapid and higher affinity thereby multiplying the signal.

The following nonlimiting examples are provided to further illustrate the present invention.

25 EXAMPLES

Example 1: Materials

Antibodies used include mAbs 7.16.4 and A11, each of which is reactive with a different epitope in the extracellular domain of p185neu. 1E1 is an IgG1 monoclonal antibody generated against the ectodomain of human p185her2/neu. rhuMAb 4D5 (Herceptin) was obtained from Genentech. The anti-phosphotyrosine monoclonal antibody PY99 was obtained from Santa Cruz Biotechnology (Santa Cruz, CA). The cell line B104-1-1 was derived from NIH3T3 cell by

expressing rat oncogenic p185neu. The expression level of p185neu in B104-1-1 cells was determined using an ^{125}I -labeled anti-neu mAb binding assay. NR6, negative for both EGFR and p185neu, was a subclone from NIH3T3. T6-17 was derived from NIH3T3 by over-expressing the human p185her2/neu receptor. These cell lines were all cultured in Dulbecco's Modified Eagle's medium (DMEM) containing 10% fetal bovine serum (FBS, Hyclone) at 37°C in a 5% CO₂ atmosphere.

Example 2: Expression and Purification of His-tagged 7.16.4

- 10 LB media (150 ml) containing 50 µg/ml ampicillin was inoculated with a 15 ml overnight culture of *E. coli* DH5 α and maintained at 30°C until an optical density of 0.5 (600 nm) was obtained. Isopropyl-β-(D-thiogalactopyranoside) (IPTG) was added at a final concentration of 1 mM to induce
- 15 His-tagged 7.16.4ScFv. After 3 hours, cells were harvested and lysed by freezing and thawing and resuspended in 10 ml of urea lysis buffer (10 mM Tris-Cl, pH 8.0, 0.1 M NaH₂PO₄, 1 M NaCl, 8 M urea) supplemented with 0.5 mM phenylmethylsulfonyl fluoride, 2 µM pepstatin A, and 2 µM
- 20 leupeptin. The insoluble cellular debris was removed by centrifugation (12,000 x g for 15 minutes, followed by 12,000 x g for 30 minutes). The clarified supernatant was mixed with 2 ml of Ni-NTA agarose followed by gentle shaking on ice for 1 hour. The mixture was loaded into an empty column and
- 25 unbound protein was washed with urea lysis buffer (pH 6.3) at 4°C. His-tagged protein was eluted with urea lysis buffer (pH 4.5), and eluate fractions were examined by SDS-PAGE and FACS analysis as described in Example 3. Proteins in the peak fractions were pooled and dialyzed against TKC buffer
- 30 (50 mM Tris-Cl, pH 8.0, 100 mM KCl, 10 mM CaCl₂, 1 mM EDTA, 0.1 mM PMSF).

Example 3: Confirmation of 7.16.4ScFv binding by FACS Analysis

Cell-surface antigens were detected by Fluorescence-activated cell sorting (FACS). B104-1-1 cells (about 5×10^5) were incubated (30 minutes at 4°C) in 200 μ l of FACS buffer (PBS containing 0.5% bovine serum albumin and 0.02% sodium azide) containing the purified 7.16.4ScFv. Cells were then washed in FACS buffer and incubated (30 minutes, 4°C) with anti-His antibody (Invitrogen). After this second incubation, cells were washed again in FACS buffer and further incubated with FITC-labeled IgG against mouse immunoglobulins (Sigma Chemical Co., St. Louis, MO). After washing with FACS buffer, the cell pellet was suspended in PBS buffer and processed for analysis by a FACS scan flow cytometer (Becton Dickinson). For each sample, 10,000 viable cells were gated following size (forward scatter, FSC) and granularity (side scatter, SSC) parameters and analyzed with CellQuest Software (Becton Dickinson). For competitive binding, B104-1-1 cells were first incubated with the monoclonal antibody 7.16.4 in the presence of different concentrations of 7.16.4ScFv. Cells were then washed in FACS buffer and further incubated with FITC-labeled IgG against mouse immunoglobulins (Sigma Chemical Co.) before analysis on the flow cytometer.

Example 4: Synthesis of biotinylated ds-cDNA to and streptavidin conjugates

An oligonucleotide of the following sequence (GGCTAACTAGAGAACCCACT (SEQ ID NO:1)) was synthesized with a biotin at the 5' end to allow for binding to streptavidin or avidin. Another oligonucleotide primer (GCTGGGATCTGTCTCTACAA (SEQ ID NO:2)) was derived from an internal sequence from the VCP cDNA. Using these two primers, a cDNA fragment of ~ 0.6 kb was amplified from the plasmid pcDNA-VCP. This fragment

contains a biotin at the 5' end and a T7 promotor site (TAATACGACTCACTATAGGG (SEQ ID NO:3)) used to direct the synthesis of RNA from the cDNA template through the enzymatic activity of T7 RNA polymerase. For attachment of 2.5 μ g of antibody to 10 μ g of streptavidin, a half volume of 0.8% glutaraldehyde was added to 4 μ l aliquots. The solution was mixed on a rotation device for 3 hours at room temperature. Ethanolamine (1 M; 1/20 volume; pH 7.5) was then added. The solution was mixed for an additional 2 hours at room temperature. The antibody-streptavidin complex was stored at 4°C.

Example 5: RNA Amplification Procedure

Ninety-six well microtiter plates (Nunc-Immuno Plate, MaxiSorp™) were coated with different concentrations of chimeric p185 extra-cellular domain-Fc polypeptide by incubating plates overnight at 4°C with 100 μ l of coating buffer (antibody concentration: 5 μ g/ml). Plates were then washed three times with PBS containing 0.2% TWEEN 20 (PBS-T; 200 μ l/well), blocked with PBS containing 0.5% FBS and 0.2% TWEEN 20 (200 μ l/well) for 1 hour at room temperature, and washed again three times with PBS-T (200 μ l/well). After this incubation step, plates were washed with PBS-T (six times, 200 μ l/well) and incubated with humanized anti-p185Her2 antibody 4D5-streptavidin conjugate (150 ng/ml, 50 μ l/well) for 2 hours at room temperature. Plates were washed with PBS-T (six times) and incubated with biotinylated cDNA (800 ng/ml, 0.05 ml/well) for 1.5 hours. Subsequently, plates were washed six times and RNA amplification was performed. The following reagents were added: 1X RNA amplification buffer (50 mM Tris (pH 8.3), 10 mM $MgCl_2$, 50 mM KCl, 0.5 mM Spermidine; 10 mM DTT; 750 μ M ATP, UTP, GTP and CTP; 0.5 μ l RNasin; 200 U T7 RNA. The solution was then incubated for 4 hours at 37°C. The RNA product was removed from the wells and 25 μ l was diluted with 75 μ l TE buffer and

then mixed with 100 μ l of 2000-fold diluted RiboGreen reagent. Ten minutes later, samples in the 96-well plate were excited at 485 nm, and the fluorescence emission was collected at 535 nm using a Spectra Fluora reader (Tecan, 5 Austria).

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